real friends of education, even in Yorkshire, spending as much energy to provide the Government with a reason for doing nothing as might itself have built and endowed a college.

PHYSICAL SCIENCE FOR ARTISTS[1]

III.

LET me begin my third paper by an attempt to graphically illustrate the conclusions to which I drew attention at the end of my second. These conclusions were as follows:—(1) Very complex molecules when in vibration give us light that we call white, which light, when split up by a prism, gives us a spectrum consisting of

Red
Orange
Yellow
Green
Blue
Indigo
Violet,

going from one end to the other. We will represent this by open letters (the initials of the various colours) to show that this is a case of the giving out of light.

V I B G Y O R

We next come to the second conclusion. (2) Very simple molecules give us coloured light. When this coloured light is analysed by the prism we find associated with the sensation of colour the fact that in this case the light is not continuous; we do not get a complete spectrum represented by

V I B G Y O R

but when we deal with the molecules of one chemical element we may get only

Y

in the case of another chemical element only

R

in another

V R

and so on, the letters representing that light is only given out in those parts of the spectrum represented by them, and not generally.

This we may also indicate by using black letters for the regions in which light is not given out, and white letters for those where light is emitted, thus

V I B G Y **O R**
V I B G Y O R
V **I B G Y O** R

We get bars of light here and there (the various mixtures of which produce different colours), instead of a *complete series* of bright bars (the mixture of which produces what we call white light).

The decomposition and recomposition of white light to which I have referred is really one of the most beautiful and at the same time most simple experiments in the whole range of optical science. The recomposition has lately been demonstrated by an elegant toy in the shape of a top, on which, while rotating with considerable rapidity, a circular disc of cardboard containing the different colours in their proper proportions painted in sectors is placed. A lecture-room experiment of the same form is represented in the accompanying woodcut. The various colours shown on the disc at rest to the right form white light when the disc is rapidly rotated by the handle shown in the figure.

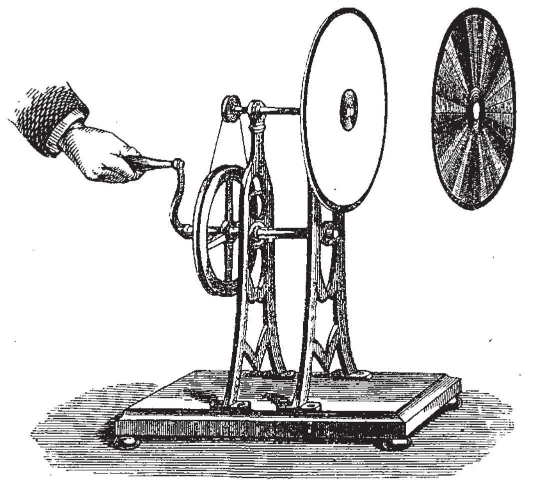

FIG. 1.—Rotating coloured disc experiment.

Two common lustres, or still better, two prisms (Fig. 2), enable the recomposition to be well seen. First arrange one prism as on the right in the accompanying diagram (Fig. 3). If the eye be placed where the second prism is to the left, to receive the light passing through the first prism, all the colours will be seen, but if the eye is replaced by a second prism as shown, the light on emerging from the second prism will be found to be reconstituted, the colours will have again commingled, to form white light. The prism, with its refracting edge

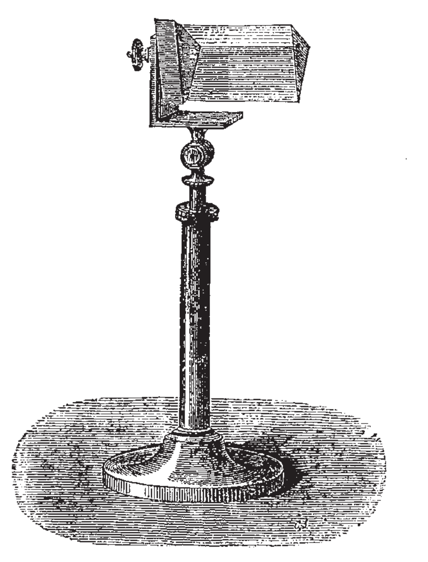

FIG. 2.—Prism mounted on stand.

[1] Continued from p. 61.

turned upwards, will have exactly undone the work done by the prism with its refracting edge turned downwards.

For the last fifteen years students have been occupied in mapping the spectra of coloured light sources, and the

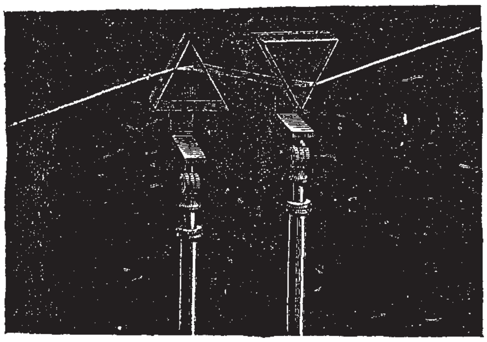

FIG. 3.—Recomposition of light.

result is now that every line in the spectrum of every substance has been thus recorded with the utmost diligence and care; so that the statement that the spectrum we get from the ultimate molecules of each different chemical substance is different, is substantiated by a most overwhelming mass of evidence.

It must be understood that in what I have stated I have represented the phenomena as being much more simple than they really are. It is quite true we can, by toning down the molecular motion, make the spectrum of each chemical element only occupy one of the spectral regions as a rule; but it is equally true that when the motion is great all the regions are filled with lines as the two following examples (Figs. 4 and 5) will show.

Here, then, is the sure and certain knowledge that we possess regarding the motions of molecules so far as one cause of the coloured phenomena observed in Nature is concerned. There is another result which has been gathered in the region of the infinitely little which helps us to another cause of these phenomena.

So far we have considered these ultimate molecules in a state of extreme vibration. As a matter of fact, so long as we are dealing with these ultimate finenesses of matter, we can still assure ourselves of the motion of the molecules when their vibrations are far less vivid. How is this accomplished?

In this way. The molecules are so apt to vibrate each in its own period that they will even take up vibrations

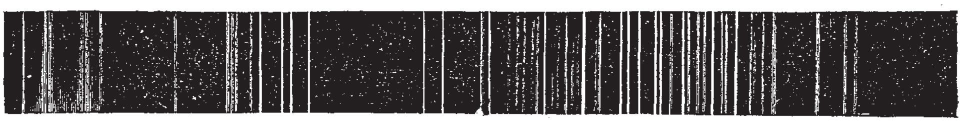

FIG. 4.—Part of the blue region in the spectrum of a mixture of incandescent aluminium, calcium, and iron vapours, showing how the images of the slit produce the appearance of bright lines.

FIG. 5.—Part of the blue region in the spectrum of incandescent iron vapour.

from light which is passing among them, provided always that the particular wave-lengths of light in which they themselves vibrate are contained in the light which they receive.

Let us imagine a case. Suppose I have at one end of a room a vivid light source giving us all the possible waves of light from red to violet.

V I B G Y O R

Also suppose that I have in the middle of the room a screen of molecules feebly emitting yellow light.

Y

What will happen? Will the light come to my eye exactly as if the molecules were not there? No; it will not. There will be a difference. What then will be the difference?

Experimentally we find that the molecules which give out yellow light have kept for their own purposes—filched so to speak, from the light passing through them—the particular vibrations which they want to carry on their own motions, and we shall have

V I B G   O R

as a result; the light comes to us minus the vibrations which have thus been utilised, as we may put it, by the screen of vapour.

We have in fact an apparently dark space which may be represented in this way

V I G B **Y** O R

When we use a spectroscope we get the continuous spectrum with a dark band across the yellow absolutely identical in position with the bright band observed when the molecules of the vapour of which the screen is composed radiated light in the first instance.

There is an experiment in the world of sound which, perhaps, may render the physics of this action clearer. If we go into a quiet room, where there is a piano, and sing a note, and stop suddenly, we find that note echoed back from the piano. If we sing another note we find that it also is re-echoed from the piano. How is this? When we have sung a particular note we have thrown the air into a particular state of vibration. One wire in the piano was competent to vibrate in harmony with it. It did so, and vibrating after we had finished, kept on the note.

One example of the phenomena observed when we use a series of molecules as a screen, I can bring

out by means of the accompanying copy of a photograph. A small mass of metallic calcium has been placed between the two poles of an electric lamp. By means of the passage of the current this mass of calcium has been raised to a very high temperature, and it has been driven to its ultimate fineness,—it has been driven, in fact, to a state of vapour competent to give out very thick bright lines in the regions marked *a, b, c* (Fig. 6.) As the vapour is gradually given off from the mass of metallic calcium, it has surrounded the interior part, and has gradually cooled as it got away from the action of the electricity. So that here we have an intensely heated mass of calcium vapour in the centre surrounded by a mass of calcium vapour which is cooling.

We have, therefore, between us and the central mass a screen of calcium molecules under exactly the same conditions as those we suggested in the screen of molecules giving out yellow light lying between us and a distant light source.

What then are the facts? On the photograph three bright broad bands of light are seen in different parts of the spectrum, which represent three of the characteristic bands of the metal calcium. I want especially to call attention to the fact that in the middle of these bands, especially in the one lettered *a*, there is a fine line of intense blackness.

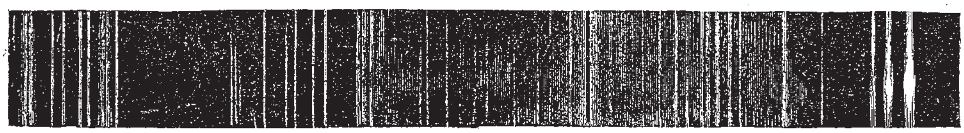

Fig. 6.—Reversal of the light of hot calcium vapour by cool calcium vapour.

That is to say, in that particular region of the spectrum there has been no light to paint an image of the slit. What has become of that light? The light has been at work, not on the photographic plate, but among the cooler exterior molecules of calcium which have used it up.

I shall now take it for granted that the great principle, that molecules absorb the light passing through them in the same wave lengths as those which they give out when vibrating on their own account, has been rendered familiar.

We must not forget that this statement is only true so long as the molecular combinations are the same, and that we only get this result in the shape of bright lines when we are dealing with the ultimate finenesses of each chemical substance, that is, when we are dealing with each chemical substance in a state of vapour.

Without going further, then, it is clear that we are now in presence of two causes of coloured light as opposed to white light. There is, so to speak, a cause of *ef*fect and a cause of *de*fect. We now know of one reason why light may be red: the luminous vibrating substance may only be competent to vibrate at that particular rate which gives us the sensation of red light. But this is not the only reason why light may be red. If we assume a screen so constituted that all the light proceeding from a white light source, *except the red*, should be absorbed by the screen, we have there a condition in which the sensation of red would again be produced. In this case it will not be the *ef*fect of red vibrations alone in the light source, but by virtue of the *de*fect of all the others which we have assumed to be absorbed by the screen.

In both cases we arrive at

V I B G Y O R

in the first case because the only light given us is

R

in the second because the screen vibrates only in

V I B G Y O

and therefore only absorbs these colours.

Red fire in a pyrotechnic display is an example of the first case. The setting or rising sun is an example of the second.

The expenditure of a very small amount of money and time will enable any one to become acquainted with many of these phenomena. The best spectroscope after all, perhaps, ease of manipulation being taken into account, is a prism held close to the eye, and a fine slit, say one-twentieth of an inch broad and two inches long, carefully cut out of a piece of tin-foil, gummed on a plate of glass. When this slit, say a foot off, is observed with the refracting angle of the prism parallel to its length, a very brilliant spectrum of a candle just in front of the slit is obtained, even though it be wanting in definition. This latter can of course be improved if a narrower slit be employed: for in spectra all impurity comes from overlapping of images, and the operations of Nature are so fine that it seems as if a pure colour, such as a pure blue or a pure red, will for ever remain an abstraction; for, however great the dispersion, the adjacent wave-lengths will remain commingled, and commingled wave-lengths define a compound colour.

Instead of reducing the width of the slit, if it is not connected with the prism by means of a tube, as it may conveniently be, the slit can be removed further from the prism. In this way we get apparently a narrower slit without any reduction in the quantity of light which passes through it to the eye. A gas flame or a candle placed in front of this slit is all that is necessary to produce a continuous spectrum.

J. NORMAN LOCKYER

CLIFFORD'S DYNAMIC

Elements of Dynamic. Part I. Kinematic. By W. K. Clifford. (London: Macmillan and Co., 1878.)

THOUGH this preliminary volume contains only a small instalment of the subject, the mode of treatment to be adopted by Prof. Clifford is made quite obvious. It is a sign of these times of real advance, and